NORTHWESTERN UNIVERSITY
Department of Civil Engineering

SEMI-ANNUAL PROGRESS REPORT No. 3

covering the period

April 1, 1965, to September 30, 1965

of work performed under

Grant NsG 605

from the National Aeronautics and Space Administration

Monitored by Mr. H. S. Wolko - RV-2

in the field of

STABILITY OF NONCONSERVATIVE SYSTEMS

submitted by

G. Herrmann, Principal Investigator

October 1965

During the period covered by the present progress report, several analytical studies were completed and manuscripts describing the work were submitted to scientific journals for publication. Following is the list of these studies with their respective summaries.

1. "Some General Considerations Concerning the Destabilizing Effect in Nonconservative Systems," authored by S. Nemat-Nasser and G. Herrmann, to be published in the Z. angew. Math. Phys. This paper may be summarized as:

> A linear system with N degrees of freedom subjected to a set of nonconservative forces which depend linearly on generalized coordinates is considered. Several theorems concerning the destabilizing effect induced by the presence of small forces which depend on generalized velocities are established. These forces may be due to viscous damping and gyroscopic effects.

2. "On the Stability of Equilibrium of Continuous Systems," authored by S. Nemat-Nasser and G. Herrmann, to be published in the Ingenieur Archiv. The summary of this report may be found in the progress report covering the period October 1, 1964, to March 31, 1965.

3. "Destabilizing Effect of Velocity-Dependent Forces in Nonconservative Continuous Systems," authored by S. Nemat-Nasser, S. Prasad, and G. Herrmann, to be presented at the Third AIAA Aerospace Science Meeting, in New York in January, 1966. This paper may be summarized as:

> A cantilevered, continuous pipe conveying fluid at a constant velocity is studied analytically. It is shown that sufficiently small velocity-dependent forces, such as internal and external damping, as well as Coriolis

forces, may have a destabilizing effect. It is also demonstrated that the Galerkin method with a two-term approximation may lead to erroneous results when velocity-dependent forces exist in the system.

4. "Energy Considerations in the Analysis of Stability of Nonconservative Structural Systems," authored by G. Herrmann and S. Nemat-Nasser, to be presented at the International Conference on Dynamic Stability in Evanston, Illinois, in October, 1965, and to be published in the proceedings of the Conference. This paper may be summarized as:

The stability of a general, discrete, linear, elastic system, with and without damping, subjected to nonconservative forces is considered. An extension of the usual energy method of stability analysis is proposed by considering the total energy of the system, including the work done by the nonconservative forces. It provides the conditions under which the loss of stability occurs statically (by divergence) or dynamically (by flutter). It is shown further that the mode of energy transfer is different in damped and undamped systems. While in the former case, the source associated with nonconservative forces supplies energy continuously to the system, energy is added in the latter case only after a certain critical value of the loading has been reached.

5. "Instability Modes of Cantilevered Bars Induced by Fluid Flow Through Attached Pipes," authored by G. Herrmann and S. Nemat-Nasser. This paper is completed but not, as yet, submitted for publication. It may be summarized as:

A cantilevered bar of uniform cross-section with flexible pipes carrying fluid attached to it is considered. It is shown that for certain cross-sections of the bar stability may be lost by either torsional divergence (torsional buckling) or torsional flutter, depending upon the location of the pipes with respect to the center of gravity of the cross-section. In addition, transverse flutter can also occur, but not transverse buckling. It is shown further that the Coriolis forces, which are present due to the motion of the fluid in vibrating pipes, may have either a stabilizing or a destabilizing effect, depending upon the parameters of the system.

Other analytical and experimental studies which are currently in progress include:

a) Bending-Torsion Instability of a Cantilevered Bar Subjected to Eccentrically Applied, Compressive, Follower Forces. An exact analysis of this problem is now being carried out. An experimental model is also under construction which will be used to test the validity and limitations of the theoretical results.

b) Flutter of a Timoshenko-Type, Cantilevered Bar Subjected to Follower Forces. In this study, the attention is being focused on the effect of damping due to shear deformations on the flutter load of the system.

c) Bending-Torsional Flutter of a Swept Wing in a High-Density Low-Speed Flow. An exact solution is being sought using also an exact expression for the Theodorsen function. This problem which is of great importance in aerospace industry has never been solved exactly. The results of an exact solution, therefore, provide an opportunity to assess both the validity of the theory in the light of the available experimental results and the limitations of previously used approximate solutions.

d) As was discussed in detail in the completed report listed above under item b, when velocity-dependent forces also exist in a nonconservative, continuous system, the widely-used Galerkin method may yield results which may be greatly in error. This problem is now under extensive study with the attention being focused on the convergence of the Galerkin method.

e) A model consisting of two articulated rigid rods with a rigid plate attached to the free end is now in operation. The free end is subjected to an air jet through a fixed nozzle which is placed uniaxially with the undeformed axis of the system. It is observed that, when a screen is attached to the end plate, the system flutters, while, when the smooth end plate is directly subjected to the air jet, it only buckles. Extensive quantitative measurements of these phenomena are being carried out and will be reported in the near future.

f) A model of a cantilevered wing subjected to a follower force which stays in the plane of the end section is under construction. It is believed that the system can lose stability by bending-torsional flutter. This model demonstrates flutter of a wing of an airplane with the jet-engine placed at its free end.